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Sounding Science Progress at NOAA

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NOAA/NESDIS/STAR

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NASA Sounding Science Meeting

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Brief History of Sounding Activities at NESDIS/ STAR

- Operational NOAA POES Soundings since 1979
- AIRS Algorithm Development 1990s – present
- AIRS Real-Time System at NOAA since 2002
- Adapted AIRS to IASI Operations in 2005-2008
- Adaptation AIRS/IASI for CrIS/ATMS (NDE) since 2006 to present
- Validation of the IDPS CrIS/ATMS EDR Algorithm (Spring 2008 to present)
- Responsible for future upgrades to CrIS/ATMS algorithms for JPSS/IDPS (Summer 2010)

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Algorithm Development at NOAA/NESDIS/ STAR

- Operational tailoring products for the weather service
  - BUFR radiance products (all fov, 1:9 fov, warmest FOV, channels subsets, etc.)
  - BUFR cloud cleared radiance products
  - MODIS spatially convolved to AIRS FOV product (clear and cloudy)
  - Install Sung Yung Lee's volcanic SO2 flag into an e-mail alert
- Develop operational algorithms
  - Local angle correction and eigenvector regression components of AIRS algorithm.
  - Derived AIRS radiance tuning and collaborated with UMBC on the transmittance tuning currently used with AIRS V5
  - Enhanced AIRS ozone algorithm
  - Led the development and installation of AIRS SVD Averaging Kernels (with significant inspiration from Wallace McMillan and Bill Irion)
  - Developed carbon dioxide (SVD and O-E approach), carbon monoxide (O-E and SVD), methane, nitric acid, and nitrous oxide first guess and retrieval algorithms.

Vertical averaging function should be thought of as a critical component of our products

- The averaging kernel can be thought of as the noise weighted average of the channel kernel functions and is a function of scene.
- To understand if the retrieval is performing to expectations, correlative measurements (such as high vertical resolution sondes or profiles acquired by aircraft)
  - Should have similar vertical resolution (smoothed) as the retrieval products.
  - Should be "degraded" by the fraction of the prior that entered the solution (*i.e.*, in regimes were we don't have 100% information content)
  - In essence, the "truth" data is run through the retrieval filter (averaging function) to produce a profile that is directly comparable to the product derived from the instrument radiances.
- When using retrieval products the A matrix
  - Describes the correlation between parameters (e.g., vertical sensitivity)
  - Tells you how much to believe the product and where to believe the product.
  - Theoretically, the *A-priori* assumptions can be removed from the solution if we are in a linear domain.
  - Given the error covariance of the *a-priori*, $C_{j,j}$, the averaging function is related to the propagated error covariance of the retrieval.

Validation Activities at NOAA/NESDIS/STAR

- Characterization and validation
  - Developed “deep dive” diagnostic capability for retrieval algorithm
  - Developed capability to utilize NCEP and ECMWF fields for diagnostic evaluation and product characterization.
  - Utilization of operational RAOBs and ozone sondes
    - Discovered and mitigated AIRS temperature bias trend
  - Developed capability to use NOAA/ESRL flask, tower, and aircraft trace gas measurements and CarbonTracker model
- Support (and utilize) in-situ campaigns
  - Supported many field campaigns with real time products and reanalysis: START05, START08, WAVES, INTEX (via Wallace McMillan)
  - Participated and have continued AEROSE campaigns to capture validation data in tropical Atlantic.
  - As algorithm developers, we can use the scientific interaction to develop better and more useful products.
- Develop new algorithms based on user needs and lessons learned
  - Developing operational IASI/AVHRR cloud clearing based on positive research results published at CIMSS for AIRS/MODIS
  - Working with users to develop new applications and transition those to operational products.

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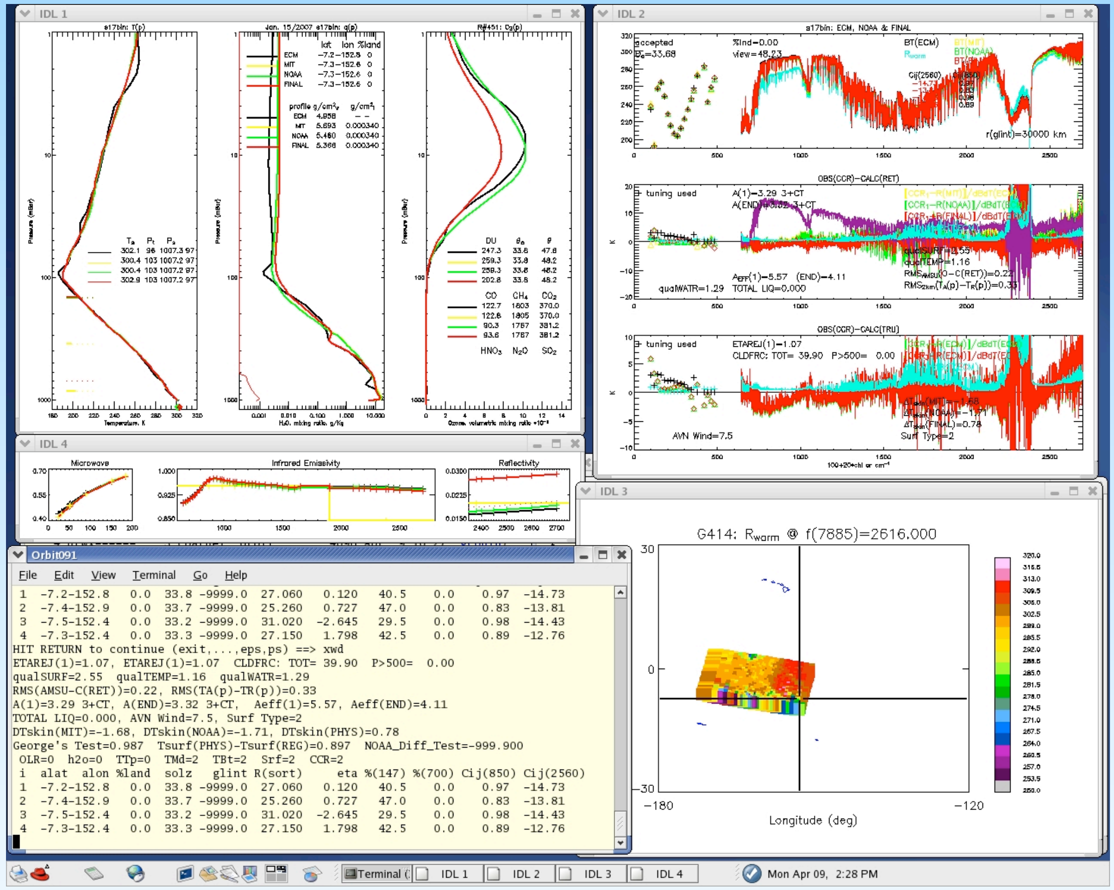
Example of “deep dive” diagnostic tools

- Launch of MeTOP Oct. 19, 2006.
- First granules provided by EUMETSAT on Feb. 12, 2007 (acquired Jan. 15, 2007)
- We ran level-2 that day - albeit not producing high quality retrievals.
- Simultaneous viewing of radiances and products for any cluster of data (including RAOB match-up’s etc.)
  - helps us to bring up the code quickly and understand issues.
- Image at right is screen snapshot taken in April 9, 2007 after a few iterations of retrieval improvement
  - Capability to easily reprocess as algorithm changes are made.
- Once problems are seen then detailed diagnostic information can be visualized for each iteration of each step of a retrieval.



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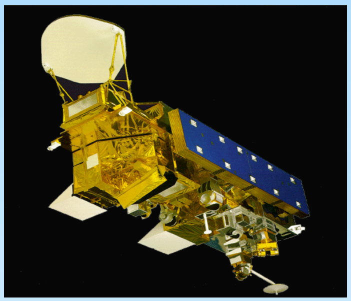
System Development at NOAA/NESDIS/STAR

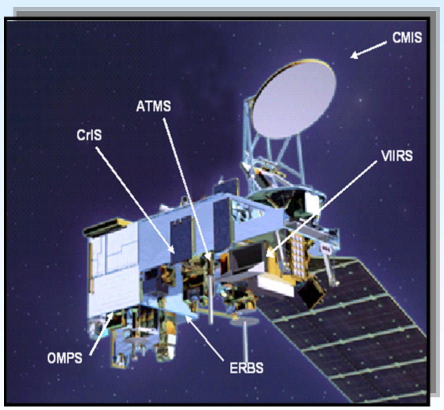
- Migrated AIRS Science Team approach to NOAA’s operational IASI/AMSU/MHS systems
  - Rapid and extremely low-cost implementation
    - Developed retrieval code to be instrument independent
      - All instrument parameters are specified in files.
    - Developed “filter” concept to operationalize science code.
      - Science code used for validation has full diagnostic support
      - Science code can fully emulate operational code
      - Operational code is guaranteed to be identical to science code
      - Extremely rapid transitions of new science to operations.
- Operational commitment to migrate AIRS/IASI code for use with NPP/JPSS (CrIS/ATMS)
- Also responsible for calibration and validation of operational NGAS level-2 (EDR) algorithm

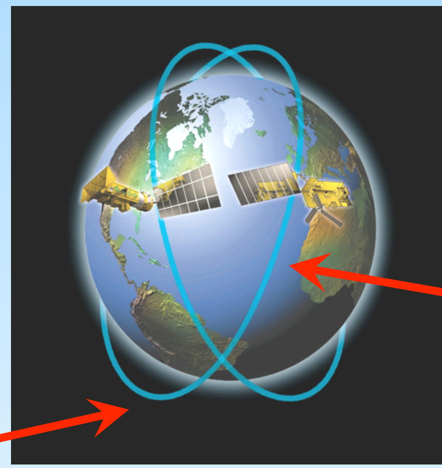
Initial Joint Polar System is a NOAA & EUMETSAT agreement to exchange all data and products.

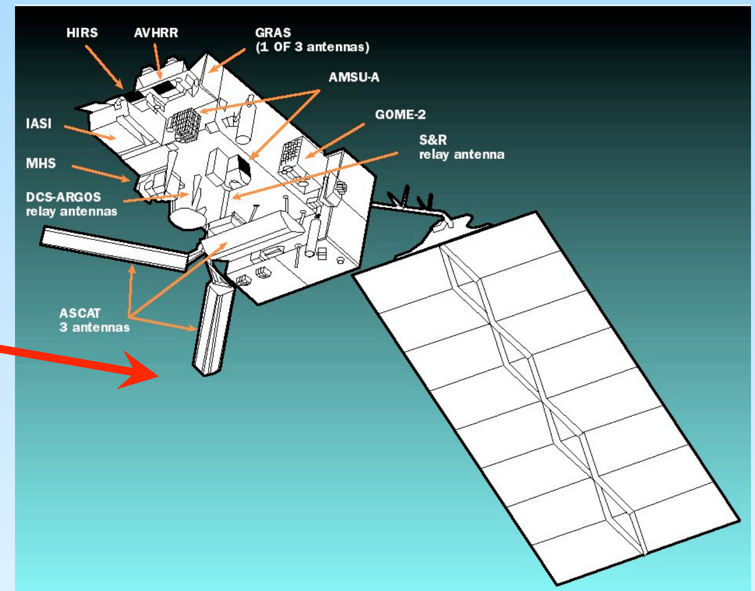
NASA/Aqua
1:30 pm orbit (May 4, 2002)



NPP & NPOESS
1:30 pm orbit
(2011, 2014, 2020)



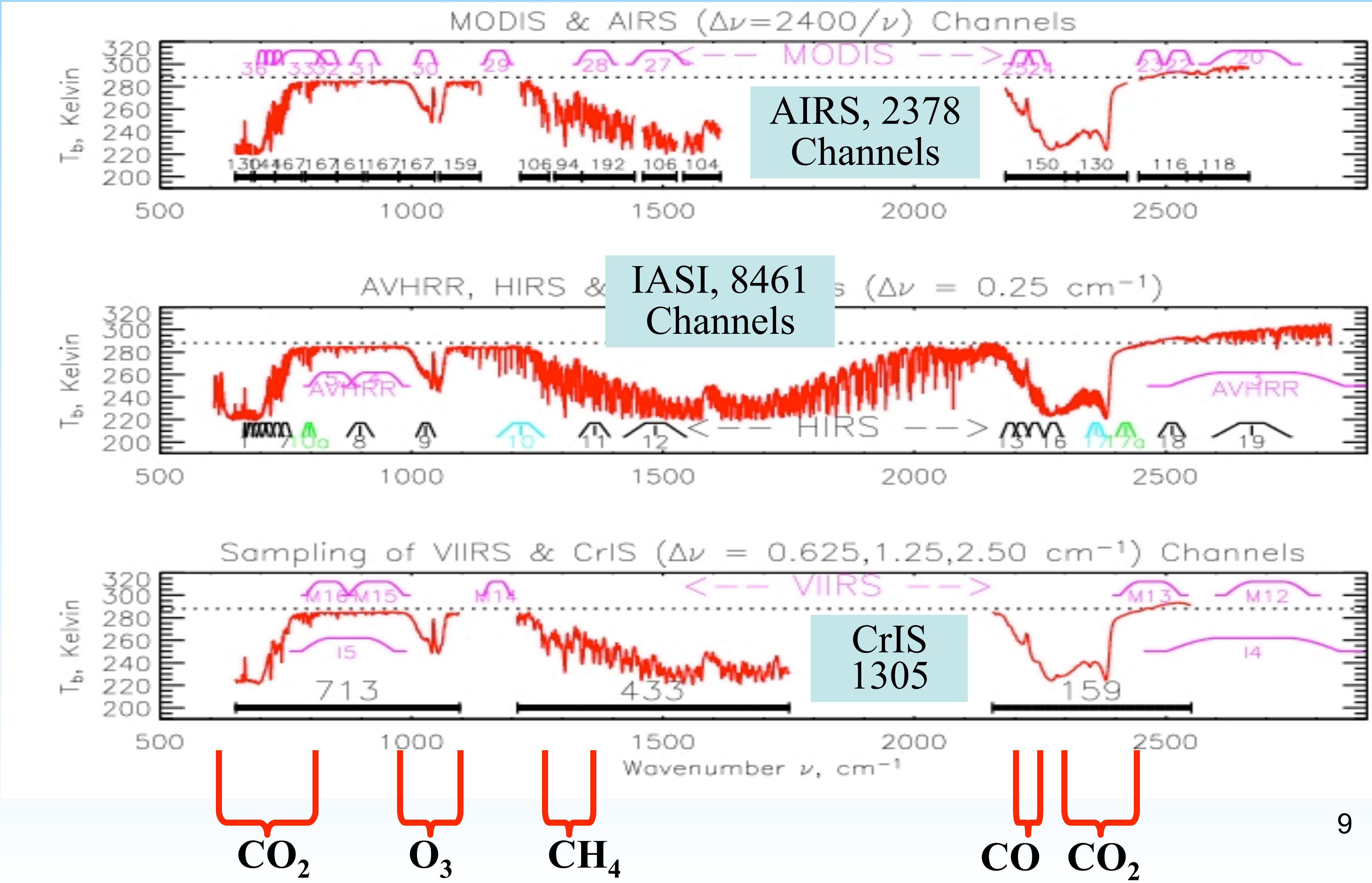




EUMETSAT/METOP-A
9:30 am orbit (Oct. 19, 2006, 2012, 2017)

20 years of hyperspectral sounders are already funded for weather applications

Spectral Coverage of Thermal Sounders (Example BT's for AIRS, IASI, & CrIS)



Why did we select the AIRS algorithm for our IASI processing system?

- Retrieval inter-comparison studies of the 1990s showed this algorithm to be fast, stable, and accurate
- NASA made large investment in validation
- Algorithm was supported by a vibrant science team
- Science code was written to be instrument independent.
  - Low risk for implementation
- We wanted to inter-compare sensor capabilities
  - Grating vs. interferometer using common algorithm/ spectroscopy
    - Follow-on to earlier simulation inter-comparisons (circa 1998)
  - Risk reduction for CrIS/ATMS

Constraints and Assumptions for the AIRS Science Team Algorithm

- One Granule of AIRS data (6 minutes or 1350 "golf-balls") must be able to processed, end-to-end, using ≤ 10 CPU's (originally 10 SGI 250 MHz CPU's). That is, one retrieval every 0.266 seconds.
- Only static data files can be used
  - One exception: model surface pressure.
  - Cannot use output from model or other instrument data.
  - Maximize information coming from AIRS radiances.
- Cloud clearing will be used to "correct" for cloud contamination in the radiances.
  - Amplification of Noise, A, is a function of scene $0.33 \le A < \approx 5$
  - Spectral Correlation of Noise is a function of scene
- IR retrievals must be available for all Earth conditions within the assumptions/limitations of cloud clearing.
- Temperature retrievals: "1 K/1-km" was the single "success criteria" for the NASA AIRS mission.

1DVAR versus AIRS Science Team Method

1DVAR	AIRS Science Team Approach
Solve all parameters simultaneously	Solve each state variable (*e.g.*, T(p)), separately.
Error covariance includes only instrument model if solution contains all trace gases, otherwise must contain error covariance for O_3, CO_2, …	Error covariance is computed for all *relevant* state variables that are held fixed in a given step. Retrieval error covariance is propagated between steps.
Each parameter is derived from all channels used (*e.g.*, can derive T(p) from CO_2, H_2O, O_3, CO, … lines).	Each parameter is derived from the best channels for that parameter (*e.g.,* derive T(p) from CO_2 lines, q(p) from H_2O lines, etc.) and avoids confounding channels
A-priori must be rather close to solution, since state variable interactions can de-stabilize the solution.	*A-priori* can be simple for hyper-spectral infrared.
Regularization must include *a-priori* statistics to allow mathematics to separate the variables and stabilize the solution.	Regularization can be reduced (smoothing terms) and does not require *a-priori* statistics for most geophysical regimes.
This method has large state matrices (all parameters) and covariance matrices (all channels used). Inversion of these large matrices is computationally expensive.	State matrices are small (largest is 25 T(p) parameters) and covariance matrices of the channels subsets are quite small. Very fast algorithm. Encourages using more channels.
Has never been done simultaneously with clouds, emissivity(ν), SW reflectivity, surface T, T(p), q(p), O_3(p), CO(p), CH_4(p), CO_2(p), HNO_3(p), N_2O(p)	*In-situ* validation and satellite inter-comparisons indicate that this method is robust and stable.

Current Status of NOAA IASI System

- For IASI we built the best system we could within our budget constraints and user requirements
  - For IASI, we were allowed to adopt an “if we built it, they will come” approach
  - But, utilization of the system (*i.e.,* user requests) drives future development
    - At NOAA, we are required to explicitly demonstrate that the product is used
      - Also required to demonstrate congressional authority to perform the work.
    - Requests for products (e-mail, community requirements), *critical* data for model or real time user, peer review papers using the product, etc. are used for justification.
  - An example: the NOAA IASI Carbon Monoxide product
    - Current implementation is AIRS v5 SVD approach (IASI=AIRS method) without averaging kernels (due to file size limitation at NCDC)
    - We developed an O-E CO retrieval (discussed at previous meetings and recommended for v6) and showed a comparison to the SVD retrieval (Maddy 2009 IEEE TGARS)
    - So it is a bit of an “chicken-and-egg” problem
      - We can’t justify adding to the system without users
      - Users avoid the product because they are unfamiliar with the algorithm

Current Status of NOAA IASI System

- Developing AVHRR/IASI product enhancements (Eric Maddy)
  - This will be installed in next operational update cycle along with new regression (v6 analog), O-E CO (w/ averaging kernels)
- Development of “standard” products, “level-3” products, re-processing, etc. is possible, but was not part of the original project’s scope
  - Many funding lines dried-up simultaneously
  - Requirements meetings, such as past 2 days, are absolutely critical to help justify spending taxpayer $$’s to add these components
- Comment (from this morning) on Support versus Standard AIRS products
  - Support product is what was minimized and represents the true products
  - Standard product is a historical artifact
    - It does not represent AIRS vertical resolution
    - It does not represent the optimal compression of AIRS level-2 information
  - Proper use of the AIRS 100 level product requires use of averaging functions
  - Maybe there is a way to make the support product more user-friendly (e.g., correct the bottom layer for surface pressure, create or provide tools for 100 layer mixing ratio’s, etc.)

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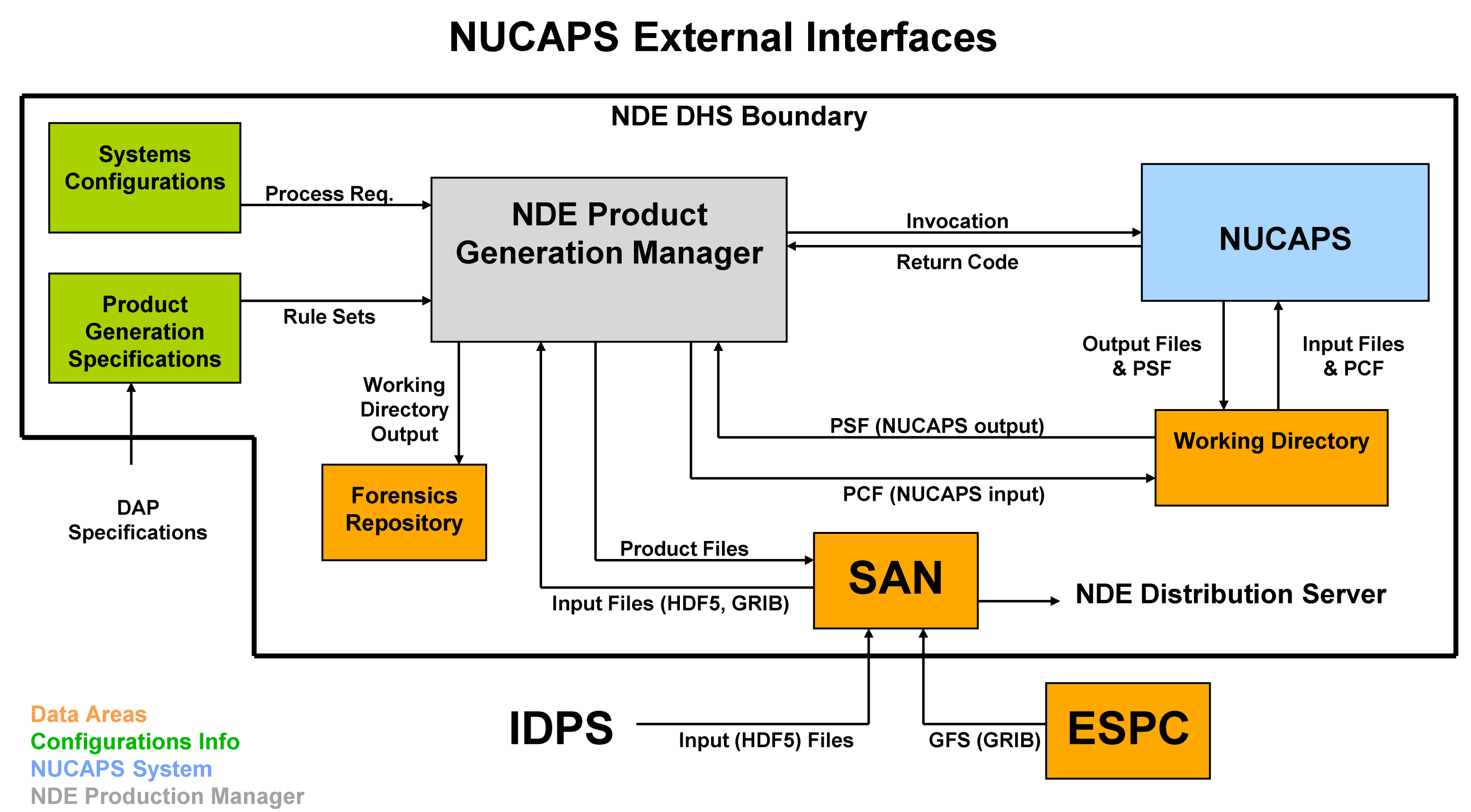
The retrieval code is a small part of the processing system (large in CPU resources)

- Upstream co-location
  - GFS
  - Operational radiosonde and other validation sites
  - Unpacking and ordering of satellite products
- Preprocessing
  - Local Angle Correction (LAC)
  - Utilize DEM & GFS to compute surface pressure, % land, and topography with IR FOV
- Schedule running of level-2 (EDR) code.
  - Large CPU resources and latency driver
  - AIRS Science Team cost both fast and stable for all scenes (has never “core dumped”)
- Distribution of data products and archive

NOAA-Unique CrIS/ATMS Processing System (NUCAPS)

- NUCAPS resides within a much larger system called the NOAA Data Exploitation System (NDE) – NOAA's NPP/ JPSS product tailoring system.



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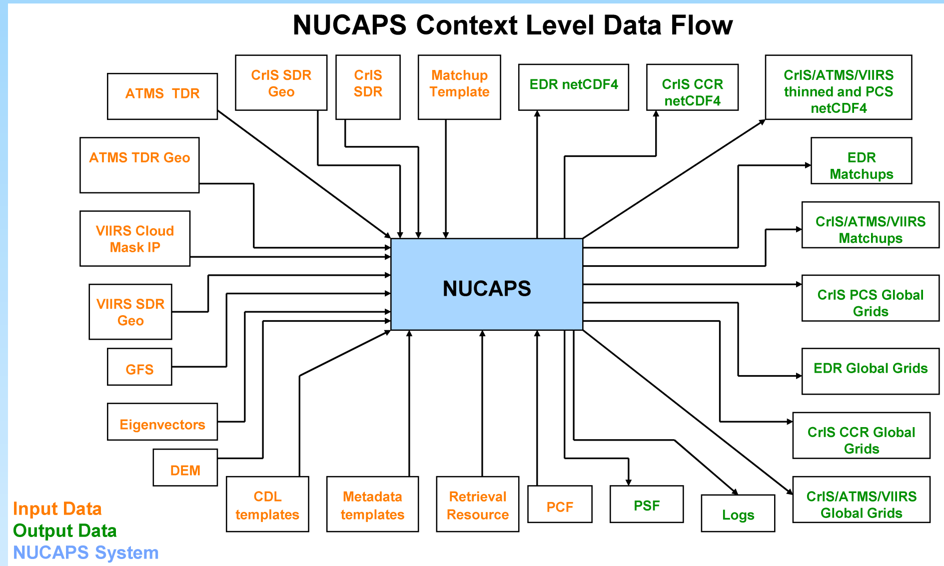
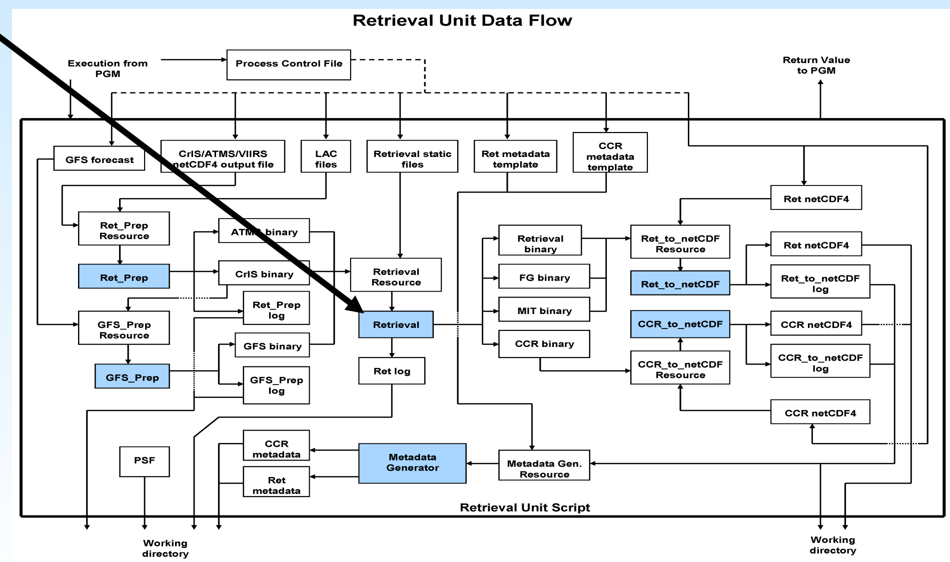
Retrieval Code is even a small part of NUCAPS System

- NUCAP’s is providing real time radiance products, gridded daily products, gridded daily subset products for monitoring and diagnostic reprocessing and volcanic SO2 e-mail alert.
- Retrieval module is one of many modules within NUCAPS.
- CrIS/ATMS retrieval code is literally the identical code for AIRS/AMSU, IASI/AMSU/MHS, and CrIS/ATMS





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Science Activities at NOAA NESDIS (Papers 2007 to present)

Topics include: Stratospheric detection of gravity waves, assimilation of cloud cleared radiances, trace gas applications (CO2, CH4, CO, Ozone), correction of MODIS instrument line shape, water vapor feedback in climate.

- Alexander, J. and C. Barnet 2007. Using satellite observations to constrain parameterizations of gravity wave effects for global models.
- Divakarla, M., C. Barnet, M. Goldberg, E. Maddy, B. Irion, W. Newchurch, X. Liu, W. Wolf, L. Flynn, G. Labow, X. Xiong, J. Wei and L. Zhou 2008. Evaluation of Atmospheric Infrared Sounder (AIRS) Ozone Profiles and Total Ozone Retrievals with Matched Ozonesonde Measurements, ECMWF Ozone Data, and Ozone Monitoring Instrument (OMI) Retrievals. J. Geophys. Res. v.113 D15308 doi:10.1029/2007JD009317, 24 pgs.
- Gambacorta, A., C.D. Barnet, B. Soden and L. Strow 2008. An assessment of the tropical humidity-temperature covariance using AIRS. Geophys. Res. Lett. v.35 L10814 doi:10.1029/2008GL033805, 5 pgs.
- Le Marshall, J., J. Jung, M. Goldberg, C. Barnet, W. Wolf, J. Derber, R. Treadon and S. Lord 2008. Using cloudy AIRS fields of view in numerical weather prediction. Aust. Met. Mag. v.57 p.249-254.
- Maddy, E.S., C.D. Barnet, M. Goldberg, C. Sweeney and X. Liu 2008. CO2 retrievals from the Atmospheric Infrared Sounder: Methodology and Validation. J. Geophys. Res. v.113 D11301 doi:10.1029/2007JD009402, 7 pgs.
- McMillan, W.W., J.X. Warner, M.L. McCourt-Comer, E.S. Maddy, A. Chu, L. Sparling, E. Eloranta, R. Hoff, G. Sachse, C.D. Barnet, I. Razenkov and W. Wolf 2008. AIRS views of transport from 12-22 July 2004 Alaskan/Canadian fires: correl. of AIRS CO & MODIS AOD with forward trajectories and comparison of AIRS CO ret's with DC-8 in-situ measurements during INTEX-A/ICARTT. J. Geophys. Res. v.113 D20301 doi:10.1029/2007JD009711, 18 pgs.
- Monahan, K.P., L.L. Pan, A.J. McDonald, G.E. Bodeker, J. Wei, S.E. George, C.D. Barnet and E. Maddy 2007. Validation of AIRS v4 ozone profiles in the UTLS using ozonesondes from Lauder, NZ and Boulder, USA. J. Geophys. Res. v.112 D17304 doi:10.1029/2006JD008181, 11 pgs.
- Pan, L., K.P. Bowman, M. Shapiro, W.J. Randel, R. Gao, T. Campos, A. Cooper, C. Davis, S. Schauffler, B.A. Ridley, J.C. Wei and C. Barnet 2007. Chemical behavior of the tropopause observed during the Stratosphere-Troposphere Analyses of Regional Transport experiment. J. Geophys. Res. v. 112 D18110 doi:10.1029/2007JD008645, 13 pgs.
- Pittman, J.V., L.L. Pan, J.C. Wei, F.W. Irion, X. Liu, E.S. Maddy, C.D. Barnet, K. Chance and R. Gao 2009. Evaluation of AIRS, IASI, and OMI ozone profile retrievals in the extratropical tropopause region using in situ aircraft measurements. J. Geophys. Res. v.114 D24109 doi: 10.1029/2009JD012493, 10 pgs.
- Sun, H., W. Wolf, C. Barnet, L. Zhou and M. Goldberg 2007. MODIS infrared channel spectral response function calibration with co-located AIRS observation. (Presentation 8.4). AMS Conf. on Meteor. Obs. And Inst. v.14 (ams.confex.com/ams/87ANNUAL/), 6 pgs.
- Wei, J.C., L.L. Pan, E. Maddy, J.V. Pittman, M. Divakarla, X. Xiong and C. Barnet 2010. Ozone Profile Retrieval from an Advanced Infrared Sounder: Experiments with Tropopause-Based Climatology and Optimal Estimation Approach. J. Atmos. Oceanic Tech. v.27 p.1123-1139.
- Xiong, X., C.D. Barnet, Q. Zhuang, T. Machida, C. Sweeney and P.K. Patra 2010. Mid-upper tropospheric methane in the high northern hemisphere: space-borne observations by AIRS, aircraft measurements and model simulations. J. Geophys. Res. 24 pgs. doi:10.1029/2009JD013796 (In Press)
- Xiong, X., S. Houweling, J. Wei, E. Maddy, F. Sun and C. Barnet 2009. Methane Plume over South Asia during the monsoon season: satellite observation and model simulation. Atmos. Chem. Phys. v.9 p.783-794
- Xiong, X., C. Barnet, E. Maddy, C. Sweeney, X. Liu, L. Zhou and M. Goldberg 2008. Characterization and validation of methane products from the Atmospheric Infrared Sounder (AIRS). J. Geophys. Res. v.113 G00A01 doi:10.1029/2007JG000500, 14 pgs.

The Future

- Two Terra/Aqua proposals are in review
  - Eric Maddy “AIRS level-2 product enhancement and error characterization”
  - Antonia Gambacorta “A multi-satellite approach to investigate the water vapor, temperature lapse rate and cloud feedback to surface temperature changes”
- Provide NASA/SPoRT an IASI “standard” product for evaluation in local forecasting.
- JPSS, JPSS, JPSS

Summary

- NESDIS/STAR provides an end-to-end capability
  - For AIRS/IASI we start with level-1 (SDR) product
  - For Microwave (not shown) we start with raw spacecraft records
- We strive to identify community needs and provide an operational service to the community.
  - We have always been open to modification of existing algorithms or the evaluation of alternative algorithms and new products.

Xiaozhen Xiong	Thurs 8:00	AIRS/IASI CH_4
Nicholas Nalli	Thurs 2:30	AIRS/IASI Validation with AEROSE
Fengying Sun	Thurs 4:30	AIRS/IASI OLR Product
Eric Maddy	Thurs 4:10	IASI/AVHRR cloud clearing QC
Antonia Gambacorta	Fri. 10:30	Status of NOAA-IASI and NUCAPS
Murty Divarkala	Fri. 10:50	CrIS/ATMS proxy datasets derived from IASI/AMSU/MHS